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Permeability, pore structure and dynamics of natural and technogeneous fluids in crystalline rocks (experimental data)

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Rock permeability is one of the main parameters governing natural and technogeneous fluid dynamics in geologic media. So, it is very important to estimate the recent permeability as well as paleo-permeability of rocks, in order to solve many important problems of geology and ecology. Unfortunately, at the present time there are no available remote geophysical methods for direct determination of the *in situ* permeability of deep-seated crustal rocks. However, rock permeability can be measured on relevant rock samples. These studies can be also carried out at high temperatures and pressures simulating *in situ* conditions of deep zones of continental crust, near-field of the depositories of high level radioactive waste (HLW) and paleogeothermal systems, as well. In this case the data interpretation - a proper offsetting of the results obtained on the small samples on geological structures and processes – is greatly important. The main trouble is that today there is no any universal rule of offsetting from the sample scale to the geological structure scale.

In this case the following manner of investigations can be proposed:

- Revealing of the main trends of rock permeability changes under high *PT* using the results of the studies on the samples.
- Revealing of the main causes and mechanisms of the parameter changes on the basis of correlation between the results obtained and the data of microstructure studies and numerical simulations.
- In case, when the bulk permeability can be similar to matrix permeability, numerical estimation of geological media *in situ* can be made using the data obtained on the samples.
- Using the data of physical experiment (measurements on the samples) as the input data in numerical one (simulating of fluid flows in geological media).

A thematic team lead by V.M. Shmonov has been performing the permeability studies in IEM RAS during the last 20 years. After all an unprecedented experimental data collection is obtained: more than 50 samples of tight low porous (0.05 – 10 %) rocks of the main lithological types of the continental crust (>2000 determinations) were studied at high temperatures and pressures. So, the main trends of permeability changes at high *PT*-parameters were found [*Smonov et al.,* 2002].

Effective pressure increase at constant temperature leads to permeability decrease.

Temperature increase at constant pressure leads to monotonous permeability increase (Fig. 1 a) or decrease (Fig. 1 b) within the entire temperature range, or to inversions on the trends: permeability firstly decreases, reaching its minimum value and than increases (Fig. 1 c, d). It should be noted that the permeability trends are complicated by abrupt threshold transitions.

Correlation of the data obtained with the results of microstructure studies under optical and electronic microscopes and with the results of numerical simulation shows that such *PT*-trends pattern in crystalline rocks is caused by their pore structure changes: first of all, by microcracking changes.

Behavior of microcracks of different shape is different when heating. Amount, apertures and interconnectivity of microcracks with high aspect ratio increase with temperature rise, with low aspect ratio, in contrary, - decrease. Under conditions of simultaneous high pressure and temperature action these processes run concurrently, as a result, inversions on the temperature trends may occur.

The main factor governing rock permeability is a degree of interconnectivity of fluid conductive clusters (pores and microcracks). Minor changes in microcracks amounts, lengths or apertures may lead to dramatic permeability changes. So, permeability temperature and pressure trends are frequently complicated by threshold transitions.

A presence of microcrack systems oriented in line with rock structure elements (for example along to foliation or fluidization etc.) is also an important factor. Such systems present strong fluid conducting clusters.

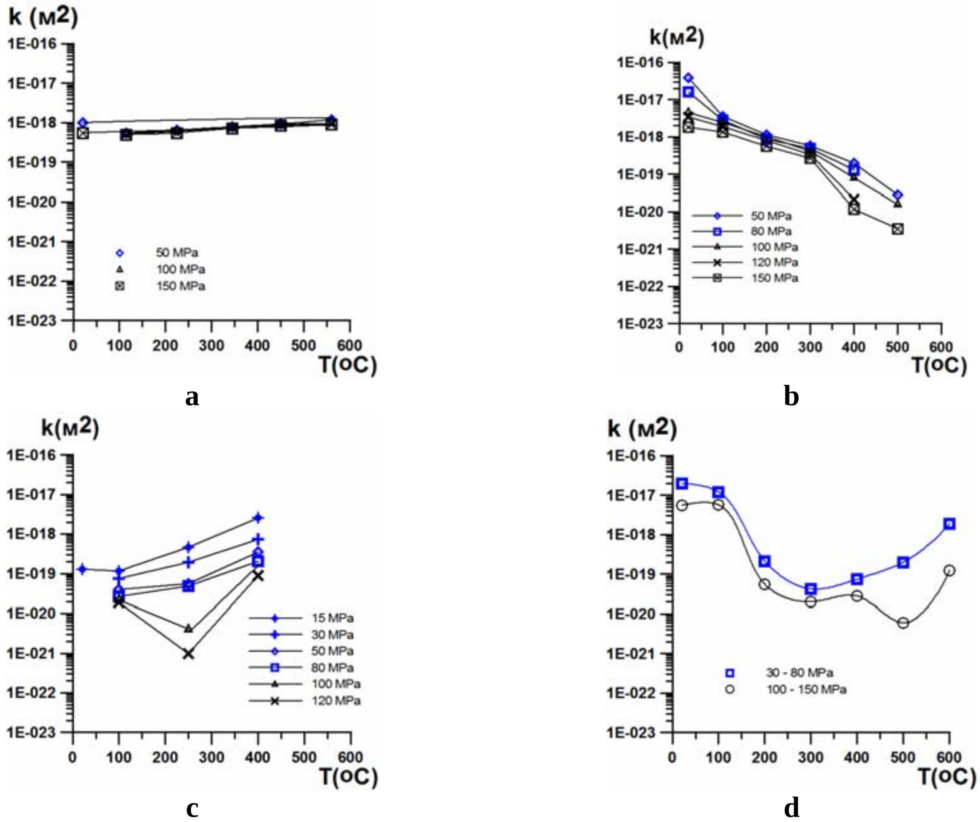
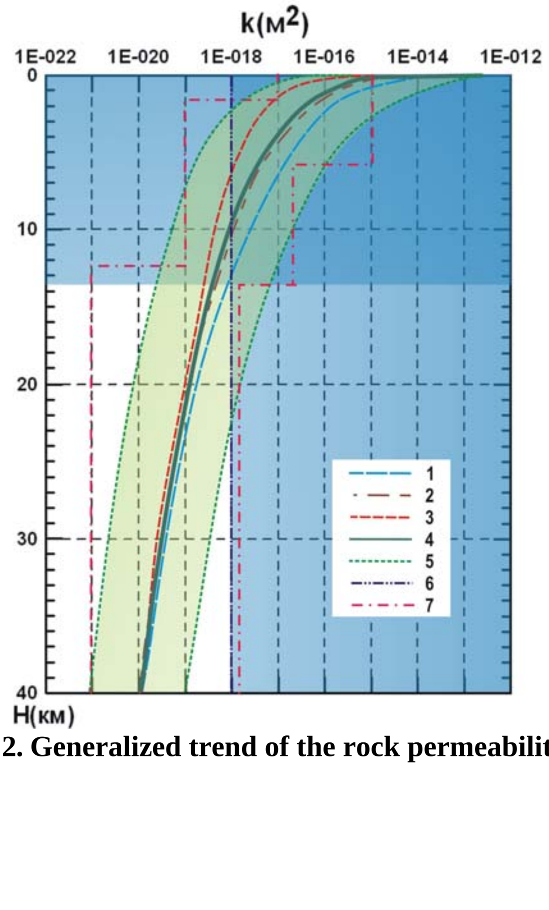


Fig. 1. Permeability vs temperature, P_{eff}=const.
a – marble, sam. 1, b – granodiorite, sam. 82066, c –granite, sam. 2., d - amphibolite, sam. 43639.



1. trend for temperature gradient of 9°C/км,
2. trend for temperature gradient of 15°C/км
3. trend for temperature gradient of 26°C/км
4. generalized trend,
5. limits of 90 % confidence interval,
6. permeability of 10^{-18} m^2 – according to D. Norton (1979)minimal value when hydrothermal systems can operate,
7. permeability according geophysical data.

Fig. 2. Generalized trend of the rock permeability of the continental crust on depth.

A generalized trend of the rock permeability of the continental crust on depth (Fig. 2) was obtained as result of experimental data processing. It was found that rock permeability (k, m^2) decreases with depth (h, км) according to the power law: $lgk = -12.56 - 3.225h^{0.223}$. A field in the boundaries of 90 % confidence interval is quite wide that means how intensive parameter variations may be. So, probably, it is more correct not to mention the specific permeability values relevant to different depth, but to mark the main tendency of permeability decrease with depth. It is significant that all curves obtained for different temperature gradients and generalized trend are in good agreement and approximate to the asymptotic value of about 10^{-20} m^2. Such permeability estimations are in good agreement with that ones which were obtained on the basis of regional ground water flows analysis and active metamorphic systems studies [*Manning u Ingebritsen,* 1999], as well. It is also significant that rocks with permeability values more than 10^{-18} m^2 – minimal value when hydrothermal systems can operate - by D. Norton (1979) – may occur down to 10-13 km of depth in accordance with our data.

The main aims of the experimental study of filtration properties carried out on the samples collected from the sites of probable underground HLW disposal: metavolcanits from the area of PA Mayak and granitoids from the area of Krasnoyarsk Mining and Chemical Combine, were to test matrix permeability of the rocks from the near-field of a HLW depository, to estimate minimal thickness of massive blocks of such rocks, providing safe HLW disposal, and to forecast possible parameter changes due to heating as a result of HLW heat generation.

Specific character of PA Mayak consists of the fact that a HLW depository for more than 2000 t of solidified wastes with total activity about $3 \cdot 10^8$ Ci has to be located in a sanitary-protective zone (SPZ) of the enterprise. Two sites, which sizes are enough for location of HLW well-depositories, are found in the SPZ. The data on effective porosity and permeability obtained on the most representative samples collected from the boreholes drilled at these sites shows that metavolcanits located outside the disjunctive zones are solid and have low porosity (mean value - 0.26 %) and permeability (mean value - $1.92 \cdot 10^{-19}$ m^2).

The results of effective porosity and permeability measurements on the main lithological types of rocks collected from the core samples of the boreholes drilled in the area of the Krasnoyarsk MCC, where HLW depositories also can be located, show that mean porosity values is 0.44 % and mean permeability values is $1.30 \cdot 10^{-18}$ m^2.

Thus, low porosity values are typical for metavolcanits and granitoids, as well. Mean parameter values are close. At the same time mean permeability value for granitoids is one decimal order higher than for metavolcanits. The difference is caused by different structure of rock pore shape. The microcracks are widely propagated in granitoids which, according V.I. Starostin (1988), belong to rocks of fragile low-solid (weak) petrophysical type in contrast with metavolcanits, which are rocks of viscous solid type. However, permeability values of granitoids and metavolcanits are low enough for safe HLW depositories location and in case when they will be placed in the massive blocks of adequate thicknesses.

In order to estimate the enough thickness of the massive blocks necessary for a HLW disposal numerical simulation of radionuclide transport by thermal convective groundwater flow was carried out. On the basis of ^{90}Sr concentration the safe depth of HLW location was found as a function of rock permeability. The data of permeability determinations on the rock samples were used as input data for the model.

In order to reconstruct a functioning of paleo-hydrothermal ore-forming system an experimental study of filtration properties of main types of Streltsovskoe ore-field was carried out. It was found that contrast difference in filtration properties of rocks is caused by character of their pore structure. It is significant that as in case of granitoids and metavolcanits mentioned above there is also no direct relationship between porosity and permeability of the rocks.

It was found that ore-bearing dacite has maximal permeability and porosity values. For the rock the maximal permeability anisotropy values reaching two decimal orders in some samples are also typical. It should be noted that the trend is also valid for minimal dacite permeability values obtained when filtration normal to fluidal texture is used to simulate a vertical flow from a deep source. Basalt porosity is a few times higher that granite porosity. In contrast, permeability of basalt is considerably lower.

During microstructure investigations it was found that in dacite microcracks and isometrical pores also contribute in total porosity. The both elements are oriented along fluidal structure effecting on permeability anisotropy which exerted a strong influence on fluid flow in volcanic rocks forming caldera mantle. Numerical simulation with use of the experimental data showed specific kinks on fluid pathways caused by rock anisotropy. Higher basalt porosity values are due to the occurrence of many isometrical pores in the rock. However, the results of sample inspection using scanning electron microscope showed that about a half of pores in basalt are dead-end. So, there is no fluid flow in a half of pore rock volume and, as a result, permeability of basalt is low. Intersecting microcracks forming interconnecting clusters contribute to granite porosity. As a result, permeability of granite is higher than that one of basalt.

During the permeability investigations at high temperatures and pressures corresponding to the conditions of ancient hydrothermal system in Streltsovskaya caldera it was found that pressure increase lead to monotonous permeability decrease. In contrast, temperature increase lead to rise of permeability in all the studied samples. It is significant that the ratio between initial permeability values kept at all *PT*: granite permeability is comparable to dacite one measured normal to fluidization. Dacite permeability along fluidization is considerably higher.

Conclusion

An experimental study of the main types of crystalline rocks at high PT-parameters corresponding to deep zones of continental crust and near-field of HLW repository *in situ* and paleo-hydrothermal systems was carried out.

It was found that rock permeability and PT-trend pattern is caused by their pore structure changes: first of all, by microcracking parameters.

Use of the physical experiment results as input data for numerical one allowed to determine safe depth of HLW well-repositories and fluid pathways pattern in hydrothermal ore-forming system of Streltsovskoye ore field.

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References

Manning C. E., S. E. Ingebritsen (1999), Permeability of the continental crust: implications of geothermal data and metamorphic systems, *Rev. Geophysics*., 37, № 1, pp. 127-150.

Norton D. (1979), Transport phenomena in hydrothermal system: the redistribution of chemical components around cooling magmas, *Bull.Mineral.*, 102, № 5/6. pp. 689-716.

Shmonov V. M., V. M. Vitovtova, A. V. Zharikov (2002), *Fluid permeability of the rocks from the Earth crust,* Nauchniy Mir, Moscow.

Starostine V. I. (1988), *Paleotectonical conditions and mechanisms of formation of ore deposits architecture*, Nedra, Moscow.